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A Smart University Gate Using Face Recognition and IoT

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Abstract: Smart security integrates innovative technology and intelligent systems to improve the safety and protection of organizations. Due to the increased populations around the world, the adoption of smart solutions for securing university premises is becoming increasingly important as the number of students and staff who use these premises is constantly increasing. Thus, the goal of this paper is to implement a smart university gate system that allows students to use either their university cards or face IDs for authorization. Our proposed solution comprises two integral components, namely a website and a smart gate system. The website serves as a platform for administrators to register new students or staff members by collecting their personal information and capturing their images. The smart gate system utilizes deep learning and machine learning techniques, specifically ResNet50 with Logistic Regression, for detecting and recognizing faces. A real-time face recognition model is deployed on a Raspberry Pi 4, which is connected to an administrator's computer via a cloud connection. The Raspberry Pi is also connected to a camera, a screen, and an Arduino microcontroller through a serial connection. The Arduino microcontroller is linked to a barcode scanner and a servo motor. It controls the gate based on the results from the face recognition model or the barcode scanner. The system facilitates a smooth entry of students, faculty, and staff to the university campus, ensuring a safer and more efficient environment.

Keywords: Smart Gate, Smart University, Arduino Uno, Raspberry Pi 4, ResNet50, Face Recognition

1 Introduction

Many organizations, like universities, are making use of intelligent security solutions due to the development of technology. The concept of a Smart University is strongly coupled with the utilization of innovative technologies, such as Artificial Intelligence (AI), Big Data, and the Internet of Things (IoT) for achieving its strategic goals [16]. Current university security systems rely on verifying people's identities through security guards or by scanning their identification cards at the university gates and premises. This situation worsens if individuals forget their identification cards, necessitating time-consuming manual registration of their information and obtaining assistance from security administrators. Such scenarios can lead to a chaotic situation, negatively affecting individuals' productivity and time utilization.

The recent research in the field of Smart Campuses [17,18,19,20], provide dimensions for transforming manual procedures to smart and automated processes, uncovering significant benefits, including increased efficiency, enhanced security, and cost savings. Smart Safety is an area which focus on using bio-metric technologies, such as fingerprints, iris scanning, and Facial Recognition (FR), for improving campus security as well as preventing unauthorized access [15]. While some touch-based bio-metric technologies, such as fingerprints scanners, are carriers of germs, other touch-less technologies, such as FR, are safer and provide highly accurate detection [7,14]. The majority of recent studies that propose intelligent gate systems, such as [26, 2,3,4,5,6,7,8,9,11], provide did not utilize FR with QR readers for cards. In contrast, this study proposes an intelligent university gate system that enables students to enter either through the scanning of their cards or through their face IDs by using Machine Learning (ML) and Deep Learning (DL) algorithms. Thus, this paper proposes a smart security system for universities' gates that utilizes FR and IoT technologies. A proof-of-concept was implemented and tested on one of Saudi Arabia's prominent universities, King Abdulaziz University (KAU).

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Figure 1 shows the general scenarios for using our system. Initially, a system administrator registers new students and uploads their face images through a web-based interface. The system will then save the new students' information in a database. Registered students trying to enter the campus, can choose between scanning their ID cards through a barcode reader or using FR through a Raspberry Pi camera. The Raspberry Pi camera is connected to a Raspberry Pi microcontroller, and the Raspberry Pi microcontroller and the barcode reader are connected to an Arduino micro-controller which is connected to a database. If the face or card is recognized, the servo motor will open the gate, and a welcome message will be displayed on the Liquid Crystal Display (LCD) screen. Otherwise, the gate will remain closed. In addition, the images stored in the database are used to train the DL model for FR using ResNet50 and Logistic Regression.

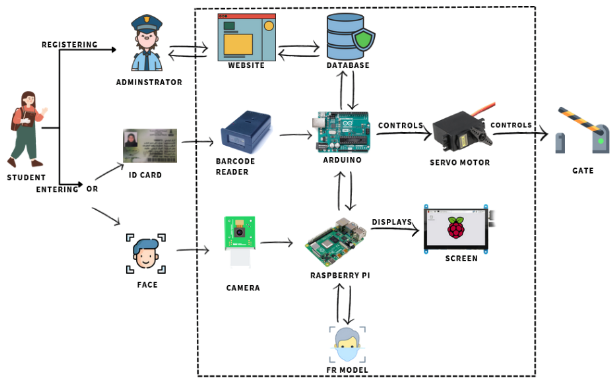


Fig. 1: Proposed System Architecture

The remainder of this paper is organized as follows. In Section 2, we review state-of-the-art smart gate approaches, and in Section 3 we present an overview of the system. Section 4 reviews the materials of the smart gate system followed by an explanation of the process of building the smart gate in Section 5. Subsequently, Section 6 discusses the different types of testing conducted on our system. Finally, Section 7 concludes the paper.

2 Related Work

Most state-of-the-art approaches in the area of smart security have proposed smart gates that utilizes IoT technology and uses deep learning or machine learning for FR. In what follows, we review relevant approaches in this area, which are also summarized in Table 1.

A recent survey [28] investigates the role of IoT in Smart Systems (SS), as well as the importance of ML in tackling security concerns. Specifically, a taxonomy of ML models is presented, categorising them as linear or non-linear depending on problem categories like classification or regression. The survey also covers numerous evaluation metrics for these models. In addition, two case studies, IoT-based Smart Campus (SC) and IoT-based earthquake Early Warning System (EWS), are presented to demonstrate the practical application of ML in IoT-based SS.

A method for automating staff attendance tracking and improving security using an intelligent gate system was proposed in [26]. This gate employs face recognition and QR codes to ensure proper identity, prevents unauthorized entrance, and includes a cleaning procedure to reduce virus transmission. The gate is made of robust materials and operated by a Raspberry Pi 4. It incorporates functions such as temperature measurement, real-time facial recognition, and 360° body sterilization using an alcohol-based solution. Practical testing at an educational institution confirmed the system's excellent efficiency for tracking attendance, limiting access, and assuring health safety. The design is cost-effective and scalable, with the option of eliminating the sanitation component after the pandemic, making it a versatile and suitable tool for varied security applications.

The authors in [27] describe the design, development, and evaluation of an IoT-based biometric recognition system called the Biometric Examinee Personal Verification System (BEPVS). The system uses facial and fingerprint recognition technologies to verify exam participants' identities. The study utilizes classic machine learning techniques for biometric recognition, specifically the Local Binary Pattern Histogram (LBPH) for face recognition and the Scale-Invariant Feature Transform (SIFT) for fingerprint identification. The authors used eight testing protocols to verify the results of the proposed approach. The protocol which uses two fingerprint scanners achieved the highest average accuracy of 96.67% and the lowest error rate of 1.82%, though it had higher costs and processing times. followed by the face recognition and fingerprint scanning with an achieved accuracy of 93.33%.

A gate pass monitoring system, proposed in [3], uses security cameras with FR. The system monitors students' behavior and provide a variety of services, including adding new students to the database, displaying students' statuses, and displaying all students' information via a Graphical User Interface (GUI). VGG16 was utilized with fine-tuning achieving an accuracy of 99.17% and without fine-tuning, the accuracy was 98.34%. Despite the system's excellent accuracy, it was unable to identify students wearing masks.

The authors in [4] uses a ResNet model to improve face recognition in intelligent door locks. The process entails using deep learning techniques to train the ResNet model while handling obstacles such as changing lighting conditions and facial emotions. The results demonstrate that the model attained an accuracy rate of around 98.7% in facial recognition tests.

A smart gate system which utilizes FR technology was proposed in [7]. The system's face verification process includes three stages; face detection, feature extraction, and face recognition. For face detection, the Viola-Jones algorithm was employed. The Principal Component Analysis (PCA) algorithm was utilized to extract the facial features, and the Support Vector Machine (SVM) classifier was then used to categorize and identify the face. The system's integrated FR algorithm has been tested on many datasets, including Yale, Yale B, and AT&T. The accuracy of the system was 97%. Although the planned technology can be installed at any gate, no details about the smart gate design were given.

A FR-based automatic door lock system was suggested in [9]. The system comprises various hardware parts which are attached to the door such as, Raspberry Pi microcontroller, Raspberry Pi camera, relay, Light Emitting Diodes (LED)s, and Direct Current (DC) motor. Once motion is detected and an image is taken by the camera, the system begins to operate. Then faces are found and identified using the HAAR cascade classifier. Two key characteristics of the HAAR Cascade classifier are its speed and excellent accuracy. The door will unlock if the face recognized matches the picture kept in the Raspberry Pi database. Through the relay, the DC motor opens the door, and LEDs are used to show whether or not the door is open.

Another FR-based door lock system was proposed in [8]. The technique begins by employing a web camera to record the face. Following that, the CNN deep learning model is used to detect the face, and the door will be unlocked if the face is identified and the user will be notified. The system was trained on photos with varying amounts of light, color, and faces seen from various angles to make sure it can distinguish faces in a variety of settings.

A secure electronic gate system for automatic car parking management is proposed in [5]. The system employs a Logitech C920 HD Pro webcam and three distinct modules, license plate, make and model of the vehicle, and facial detection to check each person's identification as they pass through the gate. The Viola-Jones method cascade object detector serves as the foundation for the face detection module. The accuracy of the system is 75%. However, three main problems can be identified. First, the reflection of light by the vehicle's windshield can lead to inaccurate facial recognition. Second, the authors used surveillance footage to generate the dataset. It features a variety of outdoor lighting and fuzzy images. Third, although it is quick, the system is unstable.

A smart gate and a website that displays the number of persons in public places during the COVID-19 pandemic was proposed in [6] as a novel method for preventing the spread of the pandemic. The intelligent gate determines whether someone is wearing a mask and takes their temperature. They employed a deep learning model-based application called mask recognition that has an accuracy rate of over 97% to assess whether someone is wearing a mask. They also utilized a Raspberry Pi to activate an alarm and open and lock a gate. However, no details were provided about the alarm activation or the used dataset.

The authors in [11] proposed a QR code-based automated gate system, with the aim of providing security solution for small businesses. The Intelligent Automated Gate System (IAGS) uses QR code technology to authenticate employee identities and manage gate access, guaranteeing that only authorised personnel enter the premises. The system receives real-time notifications about unauthorised activity, as well as records all entry and exit actions using PIR motion sensors, servo motors, Arduino microcontrollers, piezo buzzers, and cameras. The system achieves 99% QR code recognition accuracy.

Table 1 shows a summary of state-of-the-art approaches for smart gate and smart security systems, in which machine learning and deep learning models were utilized. The majority of the proposed systems used IoT technology as evident by utilizing Raspberry Pi or Arduino microcontrollers for controlling the gates opening and closing. Only a few have utilized either Raspberry Pi camera for face recognition, or Ultrasonic sensors to detect the movements of body or objects. In addition, the accuracy of the DL or ML models was not mentioned in the majority of the articles. However, VGG16 with fine tuning achieved 99.17% [3] among the approaches that reported their accuracy.

3 System Overview

A block diagram of the proposed smart gate system is shown in Figure 2. The diagram represents the main components of our system and the dependencies between them. The main components are the Gate Control (GC) module, the FR module, and the Student Data Management (SDM) module. The GC module depends on the FR and the SDM modules, and the FR module depends on the SDM module.

Within the system, the administrator is responsible for registering new students. This is achieved through the SDM module, which consists of a website for adding, deleting, and displaying students' information and images. Stored images are utilized by the FR module. The output of the FR module is then used by the Recognition via Camera sub-module of the GC module. The gate control sub-module of the GC module controls the opening and closing of the gate by employing the output of the recognition process of either the camera or the bar-code scanner.

Table 1: A Summary of State-of-the-art Smart Gate Systems

Reference	Year	Microcontroller	Camera	Sensors	Application	Card Reader	DL or ML	Algorithm	Dataset	Accuracy
[26]	2023	Raspberry Pi	Yes	- HC-SR04 Ultrasonic - MLX90614 Infrared	No	Not Used	ML	Not Mentioned	Collected Dataset	Not Mentioned
[27]	2023	- Raspberry Pi for FR - Arduino-compatible Fingerprint Scanner	Yes	Fingerprint Scanner	Web	Not Used	ML	- LBPH - SIFT	Collected Dataset	93.33%
[3]	2021	Not Used	Yes	Not Used	Web	Not Used	DL	VGG16	Collected Dataset	- With Fine-tuning = 99.17% - Without Fine-tuning = 98.34%
[4]	2021	Raspberry Pi	Yes	Not Used	Mobile	Not Used	DL	- CNN - VGG16 - VGG18 - ResNet50	ImageNet Dataset	- CNN = 100% - VGG16 = Memory Overload - VGG18 = Memory Overload - ResNet50 = 100%
[7]	2020	Arduino	Yes	Not Used	Desktop	Not Used	ML	- Viola-Jones - PCA - SVM	- Yale - Yale B - AT & T	97%
[9]	2020	Raspberry Pi	Yes	Not Used	Mobile	Not Used	ML	HAAR Cascade	Collected Dataset	Not Mentioned
[8]	2020	Raspberry Pi	Yes	Not Used	Mobile	Not Used	DL	CNN	Collected Dataset	Not Mentioned
[5]	2020	Arduino	Yes	Ultrasonic Sensor	Desktop	Not Used	ML	Viola Jone's	Collected Dataset	74.63%
[6]	2020	Raspberry Pi	Yes	Not Used	Web	Not Used	DL	Not Mentioned	Public Dataset	97%
[11]	2018	Arduino	Yes	- PIR Motion Sensor - Servo Motor - Piezo Buzzer - LED Light	Desktop	Used	-	-	-	-

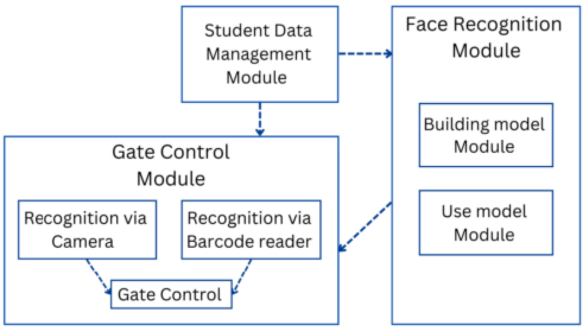


Fig. 2: Block Diagram

4 Materials and Methods

In here, we explain the data gathering methods, which comprises an interview and questionnaires. The functional and non-functional requirements of the system are also listed. In addition, the system, hardware, and software design are illustrated. Finally, the FR model is explained.

4.1 Data Gathering

In our system development, we selected King Abdulaziz University as our case study. To establish the system's requirements and understand the needs of its users, we employed various data gathering methods. This allowed us to collect data from different types of users, including security department personnel and students at King Abdulaziz University.

–Interview

A semi-structured interview was conducted to collect data from the head of King Abdulaziz University's Security Department who has over ten years of experience in the field of University Security [25]. A list of open-ended questions were prepared, and also the interviewee was encouraged explore new ideas and elaborate more on their responses. The main questions of the interview are:

- –Is the process of verifying student ID cards upon entry and exit, especially during peak times, considered a tiring task for security personnel?
- –How many security personnel are stationed at each gate?
- –What problems do security personnel face with students when requesting to present their ID cards for entry or exit?
- –Do you believe that having a university card reader system or facial recognition technology would enhance the level of security at the gates?

The interview revealed several important insights about the current security processes at King Abdulaziz University. When asked if the process of verifying student ID cards upon entry and exit, especially during peak times, is considered a tiring task for security personnel, the interviewee confirmed that it is indeed tiring, time-consuming, and stressful. They explained that the limited number of gates and the increasing number of students exacerbate this issue. If one of the gates is closed, it increases the demand on the remaining gates, placing additional pressure on security personnel during entry and exit times.

Regarding the number of security personnel at each gate, it was noted that at least four security personnel are needed at each gate to cope with the number of students. Two security personnel for verifying student ID cards upon entry and two for verifying cards upon exit. However, the interviewees believe that it is preferred to increase the personnel, especially during peak times.
The interview also highlighted the challenges security personnel face with students during the ID verification process. During the examination period, the ID verification process takes longer time than usual, due to the large number of students. Additionally, when students forget their ID cards, manual procedures must be followed to register students' information at the gate before granting campus access. These procedures are time-consuming and they cause delays in students entry and increase the chance of congestion at the gates. The situation worsens during exam periods due to increased student stress and is further exacerbated by severe weather conditions and high temperatures.
When asked if implementing a university card reader system or facial recognition technology would enhance security at the gates, the interviewee agreed that it would significantly improve gate security. They mentioned that such technology would reduce the number of personnel needed at each gate and help mitigate current issues faced by students and security personnel, such as delays and congestion.
Finally, the interviewee has mentioned a security breach point in the current system in which unauthorized people can access the campus. For example, students who should no longer access the campus due to graduation or revoked access can still enter easily if they retain their university ID cards, without being noticed by security officers. The proposed system can help mitigate such a problem by disabling those students access from the central server.

–Questionnaire

A questionnaire was designed and distributed to students at King Abdulaziz University, as they are our target users. The number of received students' responses was 120. Students ages were between 17 to 25 years old. The questionnaire was composed of eight questions. The first question was for determining the participating students age group. Then, students were asked about the number of times they forget their university ID cards and if it is mandatory to show their university ID cards at the gate in this case. After that, students were asked about the procedures followed by security personnel at the gate when students forget their ID cards and they were asked to rate the level of inconvenience that these procedures might cause. Lastly, students were asked about their opinions regarding the proposed system idea and their preference for having different options for using the smart gate.
In Table 2, an analysis of students' responses to each question is provided. The results of the questionnaire show that all participants are undergraduate students. Most students need to show their university cards to the security guards for verification when entering and exiting the university campus. In the case of forgetting the ID card, several procedures must be taken to verify the identity of the student, especially when the card is repeatedly forgotten. However, some students recall that they did not have to show the card at the gates, which demonstrated a weakens in the current security system. Many students agreed to have their faces photographed for verification when using the system. The majority of students believed that implementing such a smart gate would enhance the current entry/exit process, making it less stressful and saving time.

Table 2: Questionnaire Questions and Results

Questions	Answers	Responses
What is your age?	- 17-20 - 21-25 - Over than 25	18.5% 79.8% 1.7%
Do you usually have to show your university ID card to the security guard at the gate?	- Yes - No - Sometimes	95.8% 1.7% 2.5%
What is the procedure if you forget the card?	- Use a digital copy on MyKAU - Register information manually - Both	29.6% 21.2% 49.2%
How many times per month do you forget the card?	- 1-3 - 3-5 - 5-7 - more than 7 - I never forget it	36.3% 5.8% 0.8% 0% 57.1%
How do you rate the inconvenience of being requested to show your card at the gates and the congestion that it might cause?	- 1 - 2 - 3 - 4 - 5	3.4% 3.4% 6.7% 10.9% 75.6%
Do you think that using a smart gate system using Face ID or scan QR code will improve the entry and exit procedures for students?	- Yes - No - May be	65.5% 3.4% 31.1%
Do you prefer verifying your identity using?	- Face ID - ID Card bar-code Scan - Both - I have no preference	26.6% 42.1% 31.3% 0%
If this system is implemented, would you consent for the university to take pictures of your face to identify you when you enter the university?	- Yes - No	83.3% 16.7%

4.2 Requirements Establishment

Based on the data gathering and analysis, the main functional, and non-functional requirements were identified. The functional requirements of the system are related to the website used by system administrators and the design of the gate. The main functional requirements are as follows:

–R1. The website shall allow administrator users to register.
–R2. The website shall allow administrator users to log in.
–R3. The website shall allow administrator users to register the student into the system.
–R4. The website shall allow administrator users to display their account information.
–R5. The gate shall allow the students to enter the campus by FR.
–R6. The gate shall allow the students to enter the campus by Bar-code scanning of the university card.

The main non-functional requirements of our proposed system are as follows:

–R7. Usability: Design a usable system to achieve our goal effectively.
–R8. Accuracy: Train the system to get accurate results for FR.
–R9. Speed: The approximate time to open the gate is between 5 to 7 seconds depending on the time to recognize the student's face, which might take 2 to 3 seconds and the servo motor speed, which takes 2 to 3 seconds to open the gate.
–R10. Privacy: Apply privacy protection procedures on students' images and information.

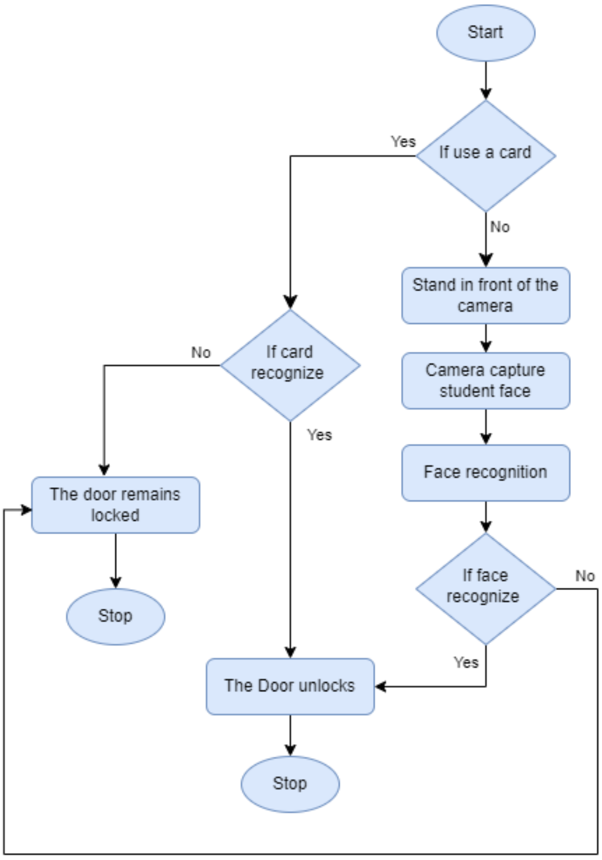


Fig. 3: Proposed framework for the smart gate

4.3 System Design

Figure 3 represents the flowchart of the system. If a student used the card to enter the campus, the gate will be unlocked when the card is recognized. Otherwise, the door remains locked. If a student forgets the card, he/she can stand in front of the camera then the camera captures the face. If the face is recognized, the door is unlocked, and if the user face is not recognized, the door remains locked.

Figure 4 shows the sequence diagram for the administrator user, which includes logging into the system, registering new students, and training the model. The diagram starts with the administrator user logging into the website by entering his/her ID and password. If the user is not found in the system, an error message will appear. If the user was successfully found in the system, the home page appears, and the user can select the register new student option, in which the registration page appears to the user. After that, the user will be able to insert the student's data and upload five images of the student using a Graphical User Interface (GUI). When the user presses the add student's data option, all the entered information is saved. After that, the administrator signs in using her/his RealVNC account credentials, and the Raspberry Pi's desktop will appear to the administrator to transfer files, but before the user transfers files, he/she must compress the files and then send them using VNC viewer. Once the files are transferred, the user will be able to train the model.

Figure 5 illustrates the sequence diagram for the student when he/she enters the campus via FR. It starts with the student standing in front of the camera, then the camera captures the student's face. The captured image is sent to the Raspberry Pi in order to be processed and then sent to the model for recognizing the student's face. If the student's face is not recognized by the model the system sends an unknown label to the screen, then the screen displays the unknown label above the student's face. If the model recognizes the student's face, a welcome message appears and the Raspberry Pi sends the open message to the Arduino and the Arduino sends the open command to the servo motor to open. After 5 seconds, the Arduino sends a close command to the servo motor.

Figure 6 illustrates the sequence diagram for the student when he/she enters the campus via the university card. It starts with the student scanning the card and the bar-code reader extracting the student's ID and sending it to the Arduino. Then, the Arduino sends the student's ID to the server to be processed and searched if the student exists in the database. If the student was found in the database, the Arduino sends the student's name to

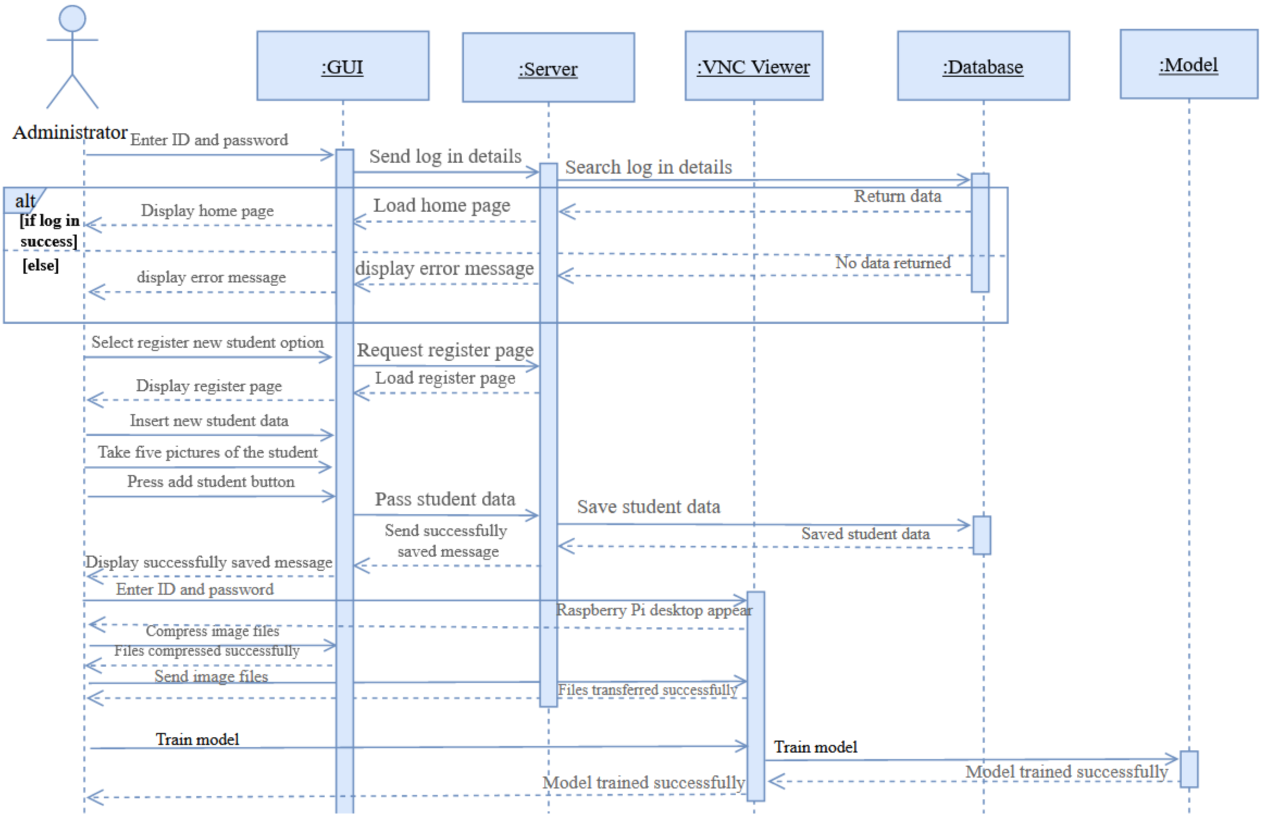


Fig. 4: Sequence Diagram - Registration

Raspberry Pi to create a welcome message with the student's name and then sends it to the screen to show the student the welcome message. The Arduino sends the open command to the servo motor to open the gate. After 5 seconds, the Arduino sends a close command to the servo motor to close the gate.

4.4 Hardware Design

For the KAU smart gate, multiple devices, including Arduino UNO, Raspberry Pi, and WiFi, were connected to create an electric circuit. This circuit compares the data on the student's university card or the captured face image to the information stored in the database, looking for a match to open the gate. Figure 7 illustrate the used electronic components in Arduino and Raspberry Pi circuits.

Raspberry Pi comes in different versions like 1G, 2G, 4G, and 8G. We are using the Raspberry Pi for the FR therefore, we chose the 8G version for its higher capacity and performance. Note that while the tasks of the Arduino can also be performed by the Raspberry Pi, we chose to dedicate the Raspberry Pi to the facial recognition (FR) part and the Arduino to the card scanner part. The reason for this separation is to ensure that if one device crashes, the other can still function and verify the student's identity. The Raspberry Pi Camera Module comes with one version that can be used to capture high-definition videos as well as pictures. Moreover, there are three sizes of LCD HDMI Display, LCD 3.5-inch HDMI Display, LCD 5-inch HDMI Display, and LCD 7-inch HDMI Display. The most suitable LCD size for the proposed system is a 7-inch HDMI display, ensuring that the displayed messages are readable..

A Raspberry Pi microcontroller was employed to execute the face recognition model, exhibit a salutation message to students on the monitor, and establish a bi-directional connection with the Arduino Uno. The installation of the operating system was facilitated by employing an Secure Digital card (SD) card and an SD card reader. To power up the microcontroller, a Type C cable is utilized. Furthermore, we utilized a micro-HDMI cable to connect the screen to the Raspberry Pi, and a micro-USB cable to power up the screen.

Arduino is an open-source platform used for constructing and programming of electronics [24]. It has many versions like UNO and MEGA, but the Mega version is expensive. Therefore, we chose UNO for the

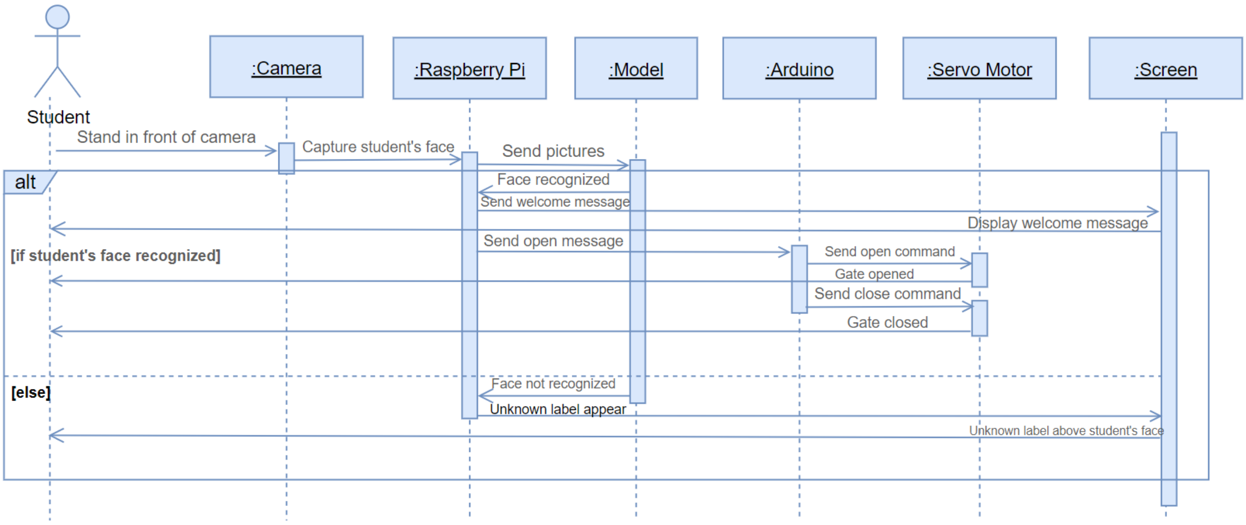


Fig. 5: Sequence Diagram - FR

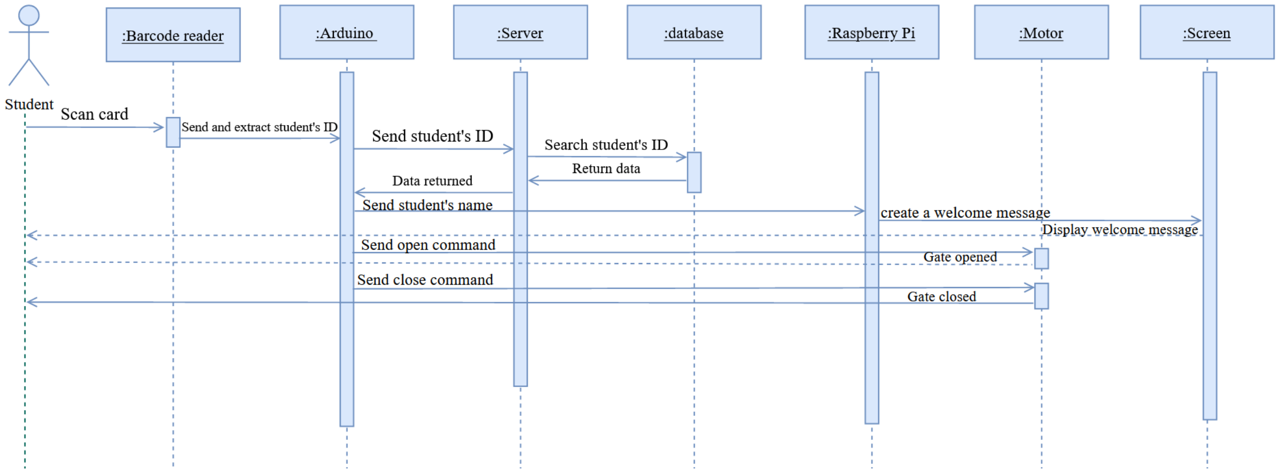


Fig. 6: Sequence Diagram - Barcode

proposed smart gate system because it is more suitable and less expensive. The servo motor can handle either 13kg, 18kg, or 20kg. Since the objective was to design a prototype as a proof of concept for the real KAU smart gate, we selected a 13kg servo motor.

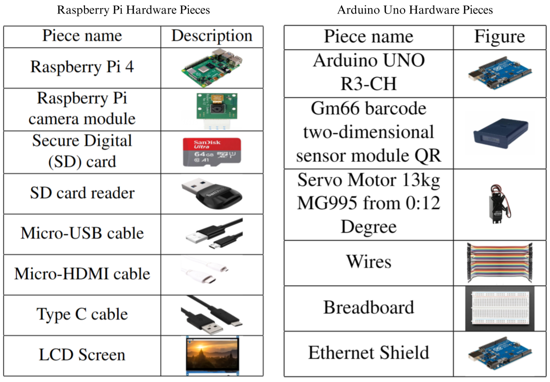
The Arduino UNO was used to control the servo motor and the scanner using wires and a breadboard, which connect each piece of the circuit to the other. Furthermore, the Ethernet shield is used to connect the Arduino to the database. This will be applied when the scanner scans the bar-code from the student card and compares it to the registered IDs in our database then a result with open/close command will be returned.

4.5 Software Interface Design

Figure 8, shows the home page of the web application, which contains the smart gate logo and some information about the system. At the top of the home page, the menu items are shown. The items include links to a number of pages, such as the add student page, delete student page, and the profile page, which displays the profile page of the user as depicted in Figure 9.

To add a new student's information to the database, the required details must be filled in on the Add Student page, as shown in Figure 10. Once completed, a message will be displayed confirming the successful addition.

On the Delete Student page, the user has two ways to delete a student, either by searching for the student's ID

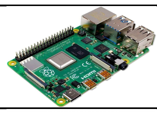
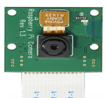


Piece name	Description
Raspberry Pi 4	
Raspberry Pi camera module	
Secure Digital (SD) card	
SD card reader	
Micro-USB cable	
Micro-HDMI cable	
Type C cable	
LCD Screen	

Piece name	Figure
Arduino UNO R3-CH	
Gm66 barcode two-dimensional sensor module QR	
Servo Motor 13kg MG995 from 0:12 Degree	
Wires	
Breadboard	
Ethernet Shield	

Fig. 7: The used electronic components in Arduino and Raspberry Pi circuits

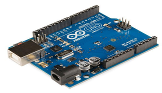
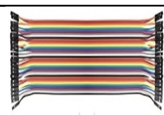
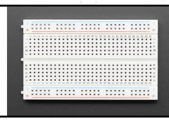
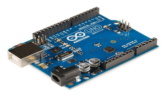
Table 3: Raspberry Pi Hardware Pieces

Piece name	Description
Raspberry Pi 4	
Raspberry Pi camera module	
Secure Digital (SD) card	
SD card reader	
Micro-USB cable	
Micro-HDMI cable	
Type C cable	
LCD Screen	

as shown in Figure 11(A) or by searching using a specific period of time as shown in Figure 11(B).

If the entered data did not meet the required conditions, an error messages will be displayed as shown in Figure 12

Table 4: Arduino Uno Hardware Pieces

Piece name	Figure
Arduino UNO R3-CH	
Gm66 barcode two-dimensional sensor module QR	
Servo Motor 13kg MG995 from 0:12 Degree	
Wires	
Breadboard	
Ethernet Shield	

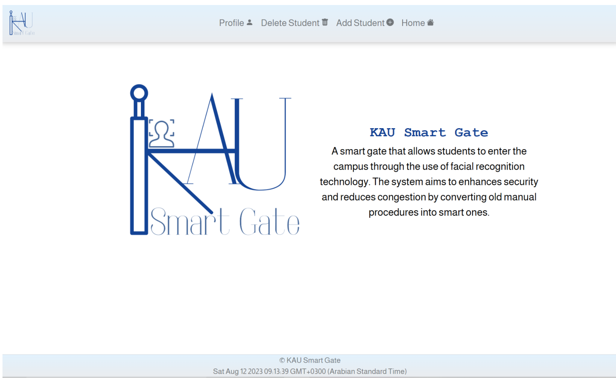


Fig. 8: Home Page

4.6 Face Recognition Model

In the FR module, the input image is entered into the system. Then the face is detected using the HAAR Cascade algorithm [21]. Next, the features of the face is extracted. After that, the output of the feature extraction step is used in the classification step to classify faces and output the name of the person. Figure 13 shows the flowchart of the FR steps.

To build our face recognition system, we used DL for feature extraction and ML for classification. For feature

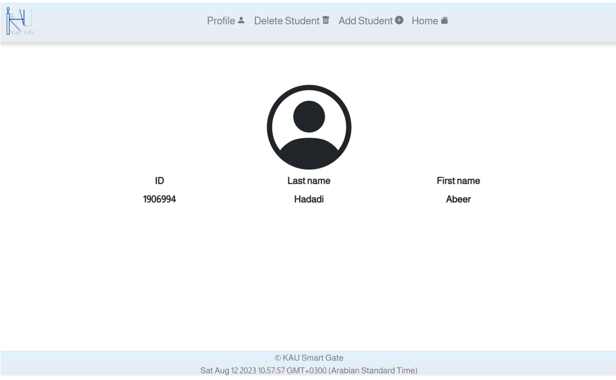


Fig. 9: Profile Page

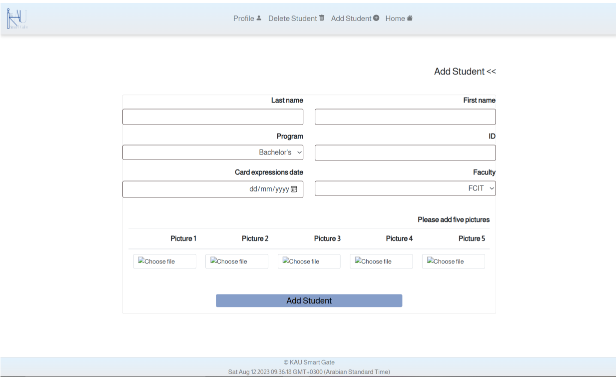


Fig. 10: Add Student Page

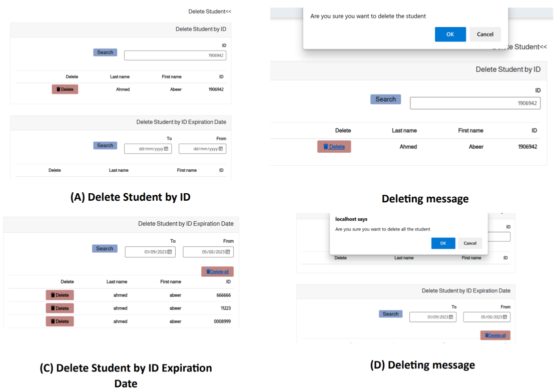


Fig. 11: Delete Student Page

extraction, we used pre-trained ResNet50 on a vggface dataset. For classification, we used Logistic Regression. We saved the label and the feature maps that were extracted from each face (embedding). In real-time, we calculate the distance between the feature maps and return the name of the person with the smallest distance.

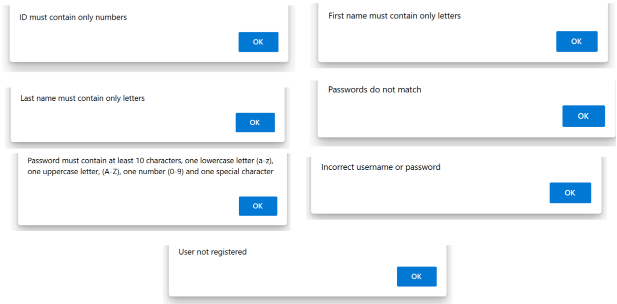


Fig. 12: User's Error Messages for not Meeting the Requirements

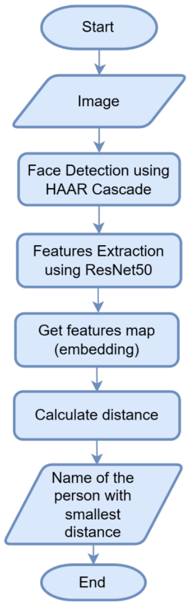


Fig. 13: FR Steps

If there is no person with the smallest distance, then the unknown is returned.

In order to evaluate the model performance, there are key classification metrics that play an important role in evaluating the model results. The performance analysis of the model was based on the evaluation metrics used for statistical tests, such as accuracy, precision, recall, and F1-Score. Our model obtained 100% accuracy, precision, recall, and F1-Score. Figure 15 shows the performance of classification on testing data.

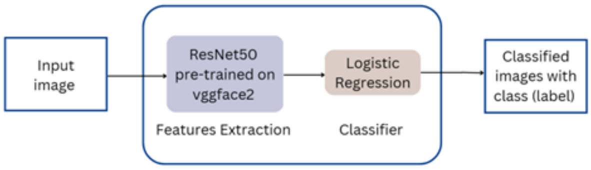


Fig. 14: Process of FR model

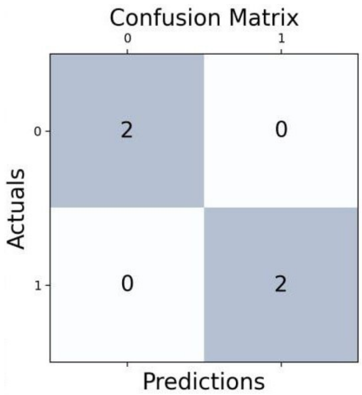


Fig. 15: Confusion Matrix

5 Building the Smart Gate

In the following sections, the design of the prototype will be discussed, with a focus on both the hardware and software components of our proposed.

5.1 Raspberry Pi

The role of the Raspberry Pi 4 is to act as a central hub or controller that connects various devices in the prototype system. Specifically, it is being used to facilitate communication between the camera, screen, administrator computer, and Arduino through its various input/output ports and networking capabilities. In the first step, we installed the Buster operating system, and we downloaded the Raspberry Pi Imager software, which facilitated the installation of various operating systems onto a micro SD card. Subsequently, we proceeded to download the zipped files corresponding to the Buster operating system. Following this, we inserted the micro SD card into the SD card reader, thereby preparing it for the installation process. Finally, we successfully installed the Buster operating system onto the SD card, completing the installation process. Then, the OpenCV, scikit-learn, NumPy, Pandas, and Mediapipe libraries for the face recognition model were installed. As a third step, the Raspberry Pi Camera module was installed by inserting the cable into the Raspberry Pi camera port. Furthermore, the camera was enabled via the Raspberry Pi settings. In the fourth step, a connection between the screen and the Raspberry Pi was established using a micro-HDMI cable, and the screen was then connected to a power outlet to provide it with power. Proceeding to the fifth step, we established a cloud connection between the administrator computer and the Raspberry Pi using the VNC server and VNC viewer, with the aim of facilitating the data transfer between the Raspberry Pi and the administrator computer. In the sixth step, the face recognition model was converted to a lighter, low-power, and faster model. The conversion was undertaken to facilitate the deployment of the model on Raspberry Pi using TensorFlow Lite. Furthermore, the facial recognition model is reliant on the live feed from the Raspberry Pi camera module. As the seventh step, the PYserial library was installed to establish a bidirectional connection between the Raspberry Pi and the Arduino using USB type-b cable. This was done to enable the Raspberry Pi to send an ”open the gate” command to the Arduino when a student is recognized by the face recognition model, and to receive the student’s name from the Arduino when the student’s ID is found in the system database. The name will later be used to generate a personalized welcome message, which will be displayed on the screen. As the final step, a multi-threaded script developed to run the face recognition model and establish a bidirectional connection between the Raspberry Pi and the Arduino.

5.2 Arduino

The role of the Arduino UNO is to act as a controller that connects the bar-code scanner, servo motor, and Raspberry Pi together. Initially, the Gm66 bar-code two-dimensional scanner had two modes: USB and URT. The USB mode is the default mode, it is when the scanner is connected to the computer through a USB cable. This mode does not serve our aim with the scanner. Our target is to connect the scanner with the Arduino’s circuit in order to upload the code to the scanner. Thus, The URT mode is what we need. However, we first have to change the mode by using the QR codes as in Figure 16.

The scanner’s black wire refers to the ground or the negative side of the battery. The scanner’s red wire refers to the 5 Volt or the positive side of the battery. Yellow and blue wires represent the sender and receiver for the scanner, where the yellow wire sends the data from the scanner and the blue wire receives data. The servo motor has many shapes of its arm. This arm plays a major role in this project as the smart gate that will respond to the open or close decision. The servo motor was programmed to move to a specific position with a specific degree. Table 5 shows the connected pins from the module to the Arduino.

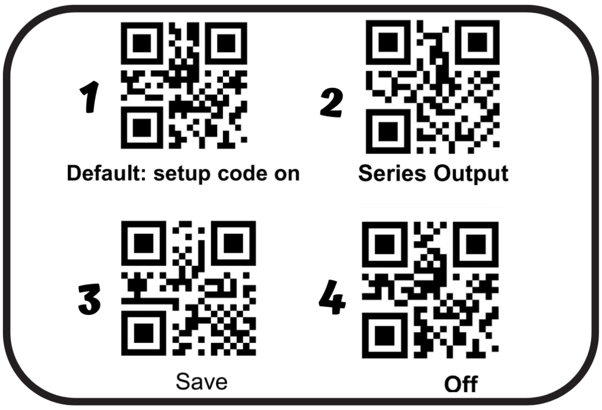


Fig. 16: IR Gm66 Bar-code Two-dimensional Sensor Module QR Mode Setup

Table 5: Pins of the Arduino Circuit

Module		Arduino
Barcode Scanner	GND	GND
	VCC	+ 5 V
	DO	D10
	DO	D12
IR Distance Sensor	GND	GND
	VCC	+ 5 V
	SDA	A0
Servo Motor	GND	GND
	VCC	+ 5 V
	DO	D7

5.3 Bidirectional Serial Communication Between Raspberry Pi and Arduino

A serial connection was establsihed between the Raspberry Pi and Arduino via a USB cable to send the open command to the servo motor that is connected to the Arduino. The Raspberry Pi sends the open command to the Arduino when the Raspberry Pi's camera captures an authorized person and the captured image is detected by the model.

5.4 Smart Gate Circuit and Arduino

Figure 17 illustrates the final circuit of our project and Figure 18 illustrates the final semblance of our smart gate.

6 Testing and Evaluation

To evaluate the performance of our proposed smart gate system, we utilized five different types of testing methods, which are unit testing, browser testing, system integration testing, heuristic testing, and usability testing. Each type of testing focus on different aspects of our system, including functionality, performance, and user experience. In the following subsections, each type of testing is discussed in more details.

6.1 Unit Testing

Unit testing was applied through the development process of our proposed smart gate system. The main objective of this testing is to ensure that each component is working correctly before integrating it with other system's components. Testing each component in isolation make it easier to identify errors and bugs and fix them at an early stage.

6.2 Browser Testing

The purpose of browser testing is to ensure that the registration web applications used by the systems's administrator function correctly across different web browsers. The testing also verifies that the application delivers a consistent user experience and performs well across various browsers, which is crucial for accessibility and usability. The tested browsers were Google Chrome, Opera, Firefox, Internet Explorer, and Safari. The registration website demonstrated optimal performance across all tested browsers, with all its functions working correctly. Figure 19 shows a sample of the test results in which the Add Student page was tested on the different browsers.

6.3 System Integration Testing

The main objective of the integration testing is to verify that different components of the proposed smart gate system function together as intended. This includes the smart gate website, Arduino, and Raspberry Pi, which were tested after integrating all parts together. Different test cases were designed to perform the system integration testing. Samples of the test cases and their results are provided below:

1. Successful entry using face recognition: The student stands in front of the camera then the camera will capture the student's face. If the student is registered in the database, student face recognition is recognized by the system. As a result, the gate will open successfully and display a welcome message with the student's name as shown in Figure 20 and 21.

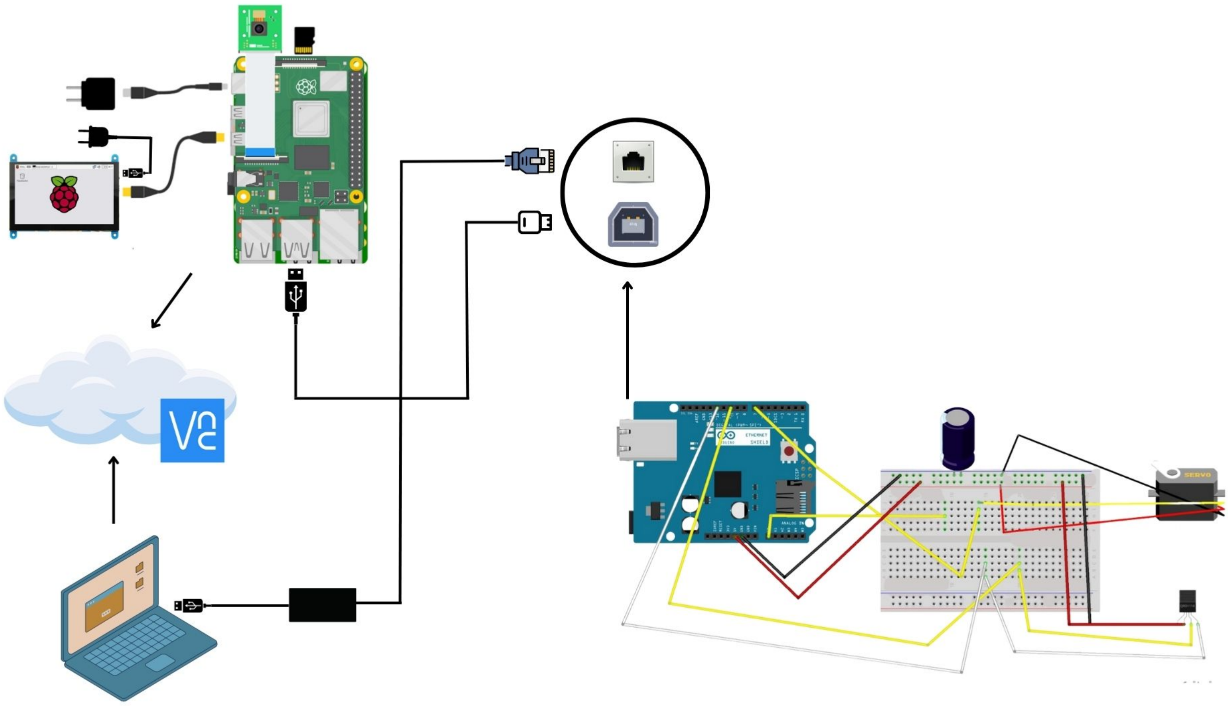


Fig. 17: Final Circuit

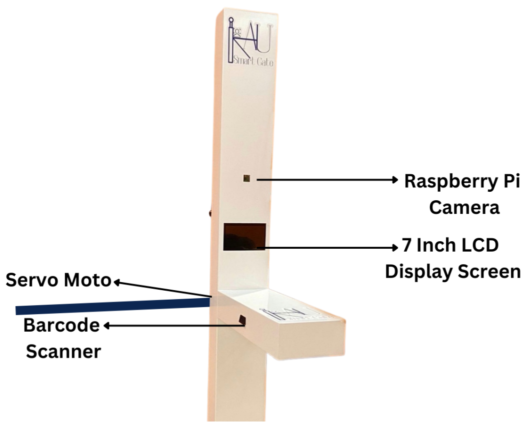


Fig. 18: Smart Gate

2. Unsuccessful entry for unregistered student: The student stands in front of the camera then the camera will capture the student's face. If the student is not registered in the database, the face recognition will be unsuccessful. As a result, the gate will remain closed and the student will be identified as "unknown" as shown in Figure 22.
3. Successful entry using the card scanner: The student scans the university card, then the scanner will scan the bar-code on the university card. If the scanned card id for a registered student, the card code will be found in the database and recognized by the system. As a result, the gate will be opened successfully and a welcome message with the student's name will be dispalyed on the LCD dispaly as shown in Figure 23.

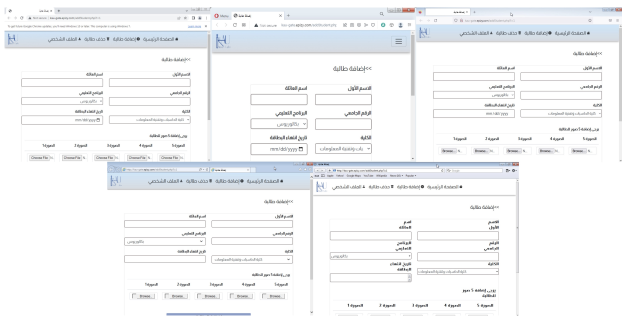


Fig. 19: Browser Testing Results

6.4 Heuristic Evaluation

The heuristic evaluation evaluates the usability of the system based on established heuristics or best practices. For the proposed smart gate system, the administrator's

Fig. 20: FR of a Registered Student and Display of Welcome Message

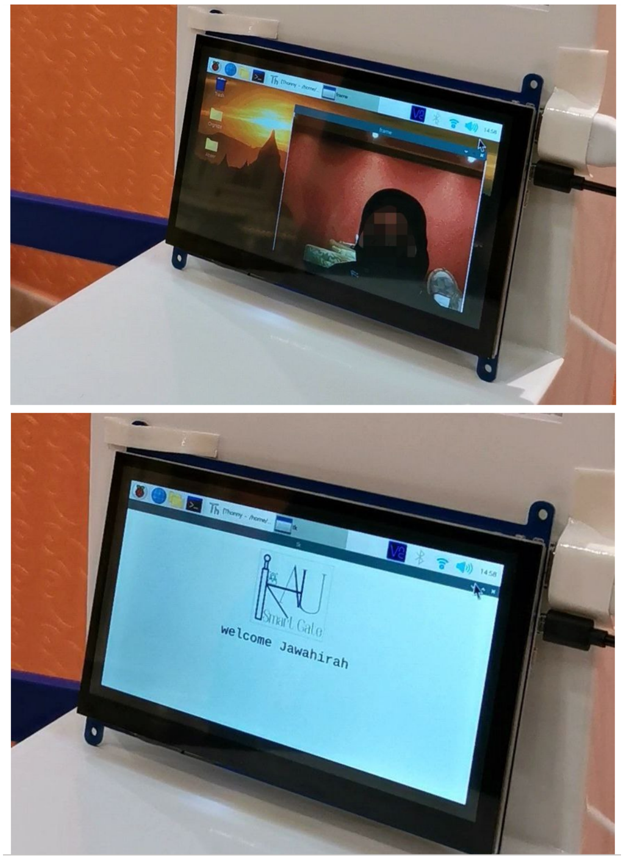


Fig. 21: FR of a Registered Student and Display of Welcome Message

Fig. 22: FR of a Non-Registered Student

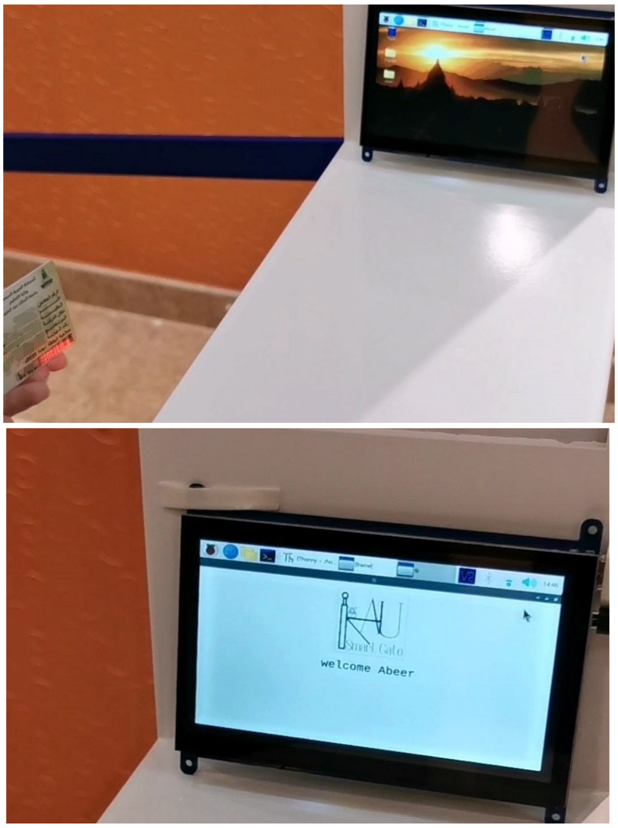


Fig. 23: Scanning Result and Welcome Message

website was evaluated using Nielsen's User Interface Heuristics [23]. The average scores achieved for all the ten heuristics are shown in Table 6. Out of the ten criteria, seven achieved a high score of 10 out of 10. However, our website failed the last criterion, criterion 10 pertaining to help and documentation. This can be improved by adding a help page that contains some documentation. Moreover, more work is needed to enhance the score of criterion 3 and criterion 6. As future work, we aim to enhance the website to raise the average score for the low-scored criteria.

Table 6: Heuristic Evaluation

No.	Criteria	Average Score of 10
1	Visibility of system status	10
2	Match between system and real life	10
3	User of control and freedom	5
4	Consistency and standards	10
5	Error prevention	10
6	Recognition rather than recall	5
7	Flexibility and efficiency of used	10
8	Aesthetic and minimalist design	10
9	Help users recognize, diagnose and recover from errors	10
10	Help and documentation	0

6.5 Usability Testing

The usability testing of the smart gate involved three security guards and three students who were needed to be present to add their face samples when being added on the website by the security guards. The users were asked to perform six tasks. In order to determine the success of these tasks, two parameters are used: the number of clicks made by the participants and the duration that it takes them to complete each task. Table 7 shows the results of the test parameters.

Table 7: Usability Testing

Task	Completion Duration	Number of Clicks
Create Account Task	1m 06.56s - 1m 32.34s	2
Login Task	13.39s - 26.12s	1
Add Student Task	1m 45.01s - 2m 45.09s	22 - 30
Delete Student by ID Task	07.13s - 22.05s	3 - 4
Delete Student by Expiration Date Task	12s - 1m 07.05s	7 - 11
Logout Task	05.38s - 11.02	2

7 Conclusions and Future Work

The concept of a Smart University is strongly coupled with the utilization of innovative technologies, such as AI and IoT with the aim of enhancing the overall campus life experience. One of the significant challenges observed in traditional university environments involves the verification of student identity when entering the campus or accessing specific facilities. This process is often hindered by issues such as overcrowding at entry points, long waiting queues, and the delays caused by the manual registration procedures undertaken by security personnel—especially in cases where students forget their identification cards. To address these challenges, this paper introduces a Smart Gate System designed to streamline and automate the student access process. The proposed system supports two modes of identity verification: the traditional card scanner and an advanced facial recognition (FR) mechanism. This dual-mode access approach ensures flexibility and reliability, allowing students to gain entry even if they forget their university ID cards, thereby reducing bottlenecks and enhancing user experience. For the facial recognition component, a hybrid AI-based solution was implemented. Feature extraction was performed using a pre-trained ResNet50 model trained on the VGGFace2 dataset, which is known for its robust performance in real-world face recognition tasks. These features were then passed to a Logistic Regression classifier, which was found to yield the highest accuracy, achieving a remarkable 100% recognition rate under the test conditions. To validate the proposed approach, a functional prototype encompassing both the hardware and software aspects of the Smart Gate System was developed. This prototype serves as a proof of concept for future integration into university infrastructure, marking a significant step toward a more intelligent, secure, and student-friendly campus environment.

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